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Effect of nitrogen, plant population, and plant maturity on potato (Solanum tuberosum L.) seed tuber production

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by

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DEDICATION

A mi madre y a la memoria de mi padre.
El amor, la formación y el apoyo
constante que de ellos he recibido
constituyen bienes invaluables en
mi vida.

INTRODUCTION

The commercial potato (*Solanum tuberosum* L.) is an open pollinated species. A homogenous cultivar must, therefore, be composed of a heterozygous genotype, preserved and multiplied by asexual means. Part or all of the tuber is used as a propagation structure or "seed" (Akeley, 1966; Stevenson et al., 1964).

Under temperate climates, cut seed tuber pieces weighing 43-57 g are recommended for planting. However, in tropical regions, potatoes are grown under more adverse field conditions and the hazard of spreading virus diseases during the cutting operation is greater. Planting whole, 32-55 mm diameter tubers is the best alternative (Thornton and Sieczka, 1980).

Whole seed tubers account for 30-50% of the total production costs. Ways of reducing costs by decreasing seed size or seed rate per unit area have been sought (Accatino and Malagamba, 1982).

Several researchers have evaluated cultural production practices that increase the proportion of seed sized tubers while maintaining seed of high quality. Early vine killing, modification of plant population and nitrogen application to the seed crop are some examples (Holmes and Gray, 1972; Maas, 1963; Murphy and Goven, 1975).

Some advantages of early vine killing as a preharvest aid have been reported. Among these are regulation of tuber size, reduction of disease, facilitation of harvest operations by hastening plant maturity, increased tuber skin suberization to reduce skinning, bruising, and storage shrinkage. However, early vine killing has been shown to reduce yield and tuber specific gravity. Tuber vascular discoloration has also been associated with this practice, especially when potato plants are under moisture stress (Findlen and Glaves, 1964; Murphy, 1963).

As plant population increases, the total tuber number and weight per unit area usually increases, while average tuber size dereases. If plant population is too high, a decline in tuber yield may sometimes occur (Holmes, 1966; Rashid, 1977; Thompson and Taylor, 1974).

High N rate stimulates the growth of haulms and delays tuberization. On the other hand, leaf-area longevity (duration of tuber bulking) is increased when high rates of N are used (Maas, 1963; Porter et al., 1982; Van Burg, 1967).

The experiments that have been carried out tending to increase the proportion of seed-sized tubers have provided mixed and inconclusive results. Most experiments considered cultural practices independently and, in only a few cases, under seed production conditions. Furthermore, the response of the potato plant to cultural practices is known to be highly influenced by the cultivar and local conditions under which the plants have been grown (Hutchinson, 1978; Toosey, 1964).

The primary objectives of this study were to evaluate cultivar differences, side-dressed N rate, in-row plant spacing, and plant maturity at harvest on yield of 32-55 mm diameter seed tubers. Also, to determine the latent effects of N side-dressed to the seed crop and vine killing on subsequent seed tuber emergence, early plant development, and tuber initiation.

LITERATURE REVIEW

Characterization of the potato cultivars

The two cultivars used in this study were Red Norland, an early red type, and Kennebec, a late white type.

'Kennebec' This cultivar was developed by the USDA and released in 1948 from a cross of two USDA seedlings, B127 x 96-95. It has midseason to late maturity. Plants are large, spreading, thick, prominently - angled stems without pigmentation. Leaves are large and dark green. Flowers are white. Tubers are large, eliptical to oblong, with shallow eyes, smooth white skin, and white flesh. It is considered a general purpose potato that bakes, boils, and fries satisfactorily and is also desirable for french frying or chipping. This is the second popular cultivar following 'Russet Burbank' and represents about 18% of the total volume of potatoes grown in the United States (Lauer et al., 1963; Thornton and Sieczka, 1980).

'Red Norland' Red Norland, an early cultivar, was developed in North Dakota and released in 1957 from the cross, Redkote x ND626. It has medium large, spreading vines with thick, prominently angled green stems and medium large, slightly closed, green leaves. The flowers are purple. Tubers are medium sized, mostly round, medium red color, with smooth skin, relatively shallow eyes, the same color as the skin, and white flesh. It produces a high percentage of U.S. No. 1 tubers and is used as a fresh market cultivar. This cultivar is the predominant early, red cultivar grown in Iowa and represents about 3% of the total volume of potatoes grown in the United States (Lauer et al., 1963; Thornton and Sieczka, 1980).

Effects of plant population on yield and tuber size

Rashid (1977), in Bangladesh, found that emergence, number of shoots per hill, and plant height increased with larger tuber size and greater plant spacing within the row. With distances from 15.2 to 38 cm, total yield was maximum at the closest spacing (15.2 cm), but yield per hill was maximum at 38 cm plant spacings. Increasing the in-row spacing reduced the percentage of tubers less than 28 mm diameter and increased the percentage of tubers greater than 45 mm diameter, whereas the 28-45 mm diameter tuber yield was not affected. Similar results have been reported by other researchers (Moorby, 1967; Morris, 1967; Nelson, 1967; Zaag, 1973).

The number of tubers initiated per unit area is determined by the amount of assimilates available, hence, by the number of stems at the time of tuber initiation. Low seed rates will result in less stems per unit area than higher ones, resulting in fewer tubers initiated. It follows that, at low populations, proportionately more assimilates will be available for daughter tubers, resulting in maximum average tuber weight for a genotype in that environment. With similar amounts of assimilates to be distributed, the average tuber weight for high plant populations would tend to be lower and more constant (Svenson, 1962).

Thompson and Taylor (1974), in Scotland, determined that, at maturity, the average tuber size for the cultivars Maris Peer and Pentland Marble fell initially as plant population increased, becoming constant at higher populations. Average tuber size was about 45% greater for 'Maris Peer' than for 'Pentland Marble'. Tuber number per square meter was similar for both cultivars at low populations, but was greater for 'Pentland Marble' when high populations were used. Total and canning sized (20-40 mm diameter) tuber weight increased over the lower part of the population range, becoming constant at about 70 stems/m^2. Canning yield represented 50% of the total tuber weight for 'Maris Peer' and over 80% for 'Pentland Marble'. Similar responses were observed in other experiments (Gray, 1971; Wurr, 1974; Varis, 1975).

In experiments with different cultivars, it has been reported that 15.2 cm (6 in) spacings of whole or cut tuber pieces of 60 g weight produced significantly higher yields of standard seed tubers (32-55 mm) than did 30.5 cm (12 in) spacings. Also, an increase in B-size (45-90 mm diameter) tubers occurred as the seed size increased and the distance between seed pieces was reduced. The trends were very similar for all cultivars evaluated (Banerjee et al., 1978; Bishop and Timm, 1968; Warren, 1958; Wilson, 1970).

Iritani et al. (1972), in Washington, and Reestman and De Wit (1959), in The Netherlands, found that, as seed became larger, the average number of stems per seed piece, percent stand, total yield, and plant size rating were also increased. The highest U.S. No. 1 yield was obtained with whole seed tubers weighing 60 g, spaced 15.2 cm (6 in) apart, while cut seed of the same size yielded slightly less. Within each spacing, the largest stem numbers per plot resulted in greatest yields.

Bremmer and Taha (1966), comparing the cultivars King Edward and Majestic in England, found that total tuber weight of 'Majestic' was highest. The high marketable weight was associated with a longer period of tuber bulking in this cultivar. Total yield tended to increase with closer spacings. Commercial yield increased as spacing decreased from 60 to 45 cm, while there was little difference between 30 and 45 cm spacings.

Total yield increased rapidly as the amount of seed increased from 454 to 680 kg/ha, but the rate of increase was lower between 680 and 907 kg/ha with only small increases above 907 kg/ha. For table stock or chipping production, any increase in yield from a planting rate above 816 kg/ha is offset by the cost of the seed. Seed growers use higher seed rates 1360 to 1587 kg/ha. Although total weight rises only a little with those high seed rates, tuber number and, therefore, the proportion of seed-sized tubers goes on increasing (Holmes, 1966).

High plant population stimulates early tuber growth and also an early maturity crop. The reason might be that, at high populations, fewer lateral shoots are formed. It may also be that less nitrogen per stem is available at high populations (Bodlaender and Reestman, 1968; Reestman, 1959).

Studies regarding nitrogen and plant population

Van Burg (1967) investigated the effect of planting population and applied N on tuber yield in two trials with crops of Sirtema seed potatoes, 'IB679' and 'IB780' in The Netherlands. On both cultivars, the response to N (120, 150, and 180 kg/ha) increased with an increase in plant population from 40,000 to 70,000 tubers/ha. This N response was first expressed in N uptake, causing the production of haulms to increase. Generally, the application of N rates over 175 kg/ha did not improve tuber yield.

Porter et al. (1982), in Maine, using the cultivars Allagash Russet, AF-186-5, and AF-205-9, found that, for all cultivars, 20.3 cm (8 in) spacings provided the best combination of marketable yield and yield of tubers 24-100 mm diameter. Seed piece spacings up to 36 cm resulted in significantly lower total yield, but slightly increased yield of tubers greater than 63 mm diameter. Nitrogen fertilization at a rate of 114 kg/ha (100 lbs/A) was sufficient to maintain high yields of the cultivars evaluated. No interaction between N fertilization and spacing was found in this study. Similar findings were reported by Panday and Ghai, 1975.

Bodlaender and Reestman (1968) conducted four experiments from 1959 to 1962 to evaluate the effect of three plant populations, 40,000, 80,000 and 160,000 plants/ha (seed size 35-45 mm), and three N levels, 0, 100, and 200 kg/ha, on tuber yield of the late potato cultivar Alpha, in The Netherlands. In the first three experiments, in which plants were harvested early in the season, total tuber weight and weight of tubers greater than 35 mm diameter increased to an optimum at 100 kg N/ha and 70,000 to 100,000 plants/ha. There were no significant differences in tuber yield between plants receiving 100 and 200 kg N/ha. In contrast, the 1962 experiment, in which plants were harvested at normal maturity, the 200 kg N/ha rate increased tuber yield significantly. In all experiments, the application of 200 kg N/ha at populations over 100,000 plants/ha caused a reduction in the yield of tubers greater than 35 mm diameter.

Maas (1963), working with 'Russet Burbank' potatoes in Canada, determined that total marketable yield was maintained but not increased significantly by plant spacings wider than 41 cm. Increasing plant spacing up to 61 cm provided a higher yield of the large tubers (300 g or over) but a reduction in the yield of small marketable (45-60 mm diameter) and very small unmarketable (less than 45 mm diameter) tubers. No significant increase on total marketable tuber production was obtained by increasing the rate of N from 61 to 123 kg/ha.

Lynch and Rowberry (1977), in Canada, found that total yield of 'Russet Burbank' was not influenced by plant population or level of fertility, while marketable yield showed a negative response to increased plant population. The interaction between plant population and level of fertility was not significant.

Applications of 114 kg N/ha (100 lbs N/A) produced practically the same yield as 170 or 227 kg N/ha (150 and 200 lbs N/A). Side-dressing part of needed N did not increase yields (Murphy et al., 1975; Sawyer and Dallyn, 1958; Timm et al., 1963; Widdowson and Penny, 1962).

Dyson and Watson (1971) evaluated the effect of four levels of N (0, 63, 125, and 251 kg/ha) on yield of potato during 1963 and 1964 in England. According to their results, N did not delay tuber initiation, but slowed the early growth of the tubers. Later in the growing season, N hastened tuber growth and the highest N rate prolonged the tuber bulking period. Leaf area index (LAI) reached maxima of 2.5 to 3.0 with the highest N rate and 1.0 with no N. The highest N rate caused an increase in leaf area duration up to 125% in both years. Uptake of N and N concentration of tuber dry weight were also increased by increasing N supply. The N concentration of tuber dry weight remained constant or increased slightly from about two weeks after tuber formation, while leaf and stem N concentration decreased rapidly.

Several workers have found that total nitrogen and NO_3-N ratios increased by increasing the N fertilizer level. Nitrogen concentration of petiole samples collected at mid-season (at flowering or about 70 days after planting) were higher and better correlated with yield than the corresponding data at late sampling (about 90 days after planting). It further appears that, of the total N and NO_3-N, the former was better correlated with yield. The authors also pointed out that the difficulty in evaluating and utilizing critical N levels (sufficiency levels), is that the procedures as to extraction, analytical method, plant parts analyzed, and time of sampling has varied considerably (Berug, 1964; Doll et al., 1971; Gately, 1971).

In petiole samples collected at mid-season, Tyler et al. (1961) proposed the NO_3-N levels of 9,000 and 6,000 ppm as sufficiency and deficiency levels, respectively, for potatoes grown in California. Corresponding values for late season were 5,000 and 3,000 ppm. However, Berug (1964), in Norway, concluded that, under the climatic conditions prevailing during his study, the values for mid-season could be about 40% lower than the above values and, at late season, NO_3-N could be nearly absent, without any reduction in yield.

In California, 'White Rose' potatoes were fertilized with isotopically labeled ammonium sulfate at rates of 0, 67, 134, 202, and 270 kg N/ha to evaluate N uptake efficiency (Tyler et al., 1983). All N applications increased yields above the control; however, the 3 higher N rates produced the same yields statistically. All N rates that maximized yields maintained levels of petiole N above 600 ppm. During the third month after planting, petiole NO_3-N dropped at rates ranging from 67 to 518 ppm/day. Tubers of plants grown in N fertilized plots, on the other hand, assimilated total N in a linear pattern during the period 82 to 125 days after planting.

Morris (1967), in England, showed that external supplies of inorganic N applied to seed tuber pieces reduced the competition between sprouts. Furthermore, experiments in which the N reserves of the seed have been varied by growing the seed crop in soils of different fertility showed that increased N reserves in the seed tuber produced more rapid sprout growth, earlier emergence and foliage development. The effect of such differences in seed performance on yields of tubers at maturity are generally small and often variable (Reichard, 1964; Schepers et al., 1969).

Gray (1974), in three experiments involving 3 early maincrop cultivars in England, explored the effect of N fertilizer (0-301 kg N/ha) applied to seed crops on seed performance and the growth of the subsequent early commercial crop. The tuber N content ranged from 1.1 g/100 g dry matter to 1.6 g N/100 g for seed tubers obtained from crops grown at 0 and 201-301 kg N/ha. Seed of cultivar Maris Peer from crops given 100 kg N/ha in 1969 produced commercial yield 10% and 24% higher than those obtained by seed from crops given 0 and 201 kg N/ha. No effects of fertilizer applied to the seed crop on subsequent growth were observed in the other two experiments.

Chemical vine killing as a preharvest practice

Efficient early vine killing reduces the amount of skinning and bruising during harvesting and storing of the crop. Early in the season when plants are actively growing, three or more weeks are required between the application of the vine desiccant and harvest for satisfactory vine killing and tuber skin suberization. Later, as plants approach maturity, less time is required. Killing vines early, however, is likely to reduce yields (Findlen and Glaves, 1964).

Murphy (1963), in Maine, reported that killing potato vines before tubers start to approach physiological maturity has a tendency to depress specific gravity. Vascular discoloration also tends to occur, especially when plants are grown under low soil moisture conditions or when high rates of herbicide are used. Paraquat at 2.5 kg ai/ha (1.0 lb/A) has been reported as one of the most effective herbicides in killing potato vines and weeds before harvest (Ahrens, 1975; Murphy and Goven, 1975; Sieczka, 1976).

Potato tubers from three vine killing trials were cut and placed in unsterilized soil to evaluate their susceptibility to breakdown (Sieczka, 1976). The results indicated that high rates of Paraquat (1.0 kg ai/ha) applied to vigorous immature potato vines increased tuber rot. Uncut tubers from the same plots, stored at 4, 10, and 16 C, did not break down and produced normal sprouts at 10 and 16 C. Goven (1976) killed plants in Maine with Paraquat and Diquat at 0.6 and 1.1 kg ai/ha and found that none of the desiccants affected emergence of plants or yield of tubers when seed from treated plants was planted the following year. The highest rates of the desiccants caused some brown, internal discoloration of the tubers.

Control of virus and *Phytophthora infestans* have been observed with Diquat and Paraquat as early vine desiccants in Canada (Wright and Hughes, 1964).

Several researchers have reported that seed harvested immature had a slightly shorter dormant period and more rapid sprout growth than mature seed (Hutchinson, 1978; O'Brien and Allen, 1975).

Holmes and Gray (1972), in Scotland, and Murphy et al. (1967), in Maine, found no effect of the time of defoliation of the seed crop on subsequent commercial yield. On the other hand, in other experiments, it has been reported that immature seed gives higher yield than mature seed (Chase, 1977; Hossain and Rybacek, 1978; Maas, 1971).

Godwin et al. (1969) evaluated the effects of site of production, time of harvest, and postharvest treatment on subsequent crop growth and yield of seed potatoes 'Arran Pilot' grown in England during 1962 and 1963. Their results were not consistent over both years, though they found that, in the first year, early harvested seed outyielded mature seed, whereas, in the second year, the reverse happened. They also found that physiological aging of the seed was little affected by area of production or time of harvest and more strongly affected by varying the storage conditions.

Wurr (1978), in England, concluded that the higher sprout length and tuber yield of immature seed tubers appeared to be attributable to an earlier dormancy break of the seed tuber.

According to Toosey (1964), the rate of physiological aging of the tuber depends jointly on 1) date of initiation of the parent plant, 2) environmental conditions during field growth, 3) state of harvest, and 4) storage temperature. He further claimed that the effects of prestorage conditions can be modified greatly, or even eliminated, if suitable temperature adjustments and sprouting techniques are adopted and the seed is placed in a controlled environment immediately after harvest.

SECTION I. EFFECTS OF SIDE-DRESSED NITROGEN APPLICATION, IN-ROW PLANT SPACING, AND PLANT MATURITY AT HARVEST ON POTATO (*Solanum tuberosum* L.) SEED TUBER PRODUCTION

PROCEDURES

The experiment was conducted on a central Iowa silty clay loam soil with 4.6% organic matter, a CEC of 19 meq/100 g, 265 kg/ha of exchangeable K, and 50 kg/ha of P. The previous crop was an annual rye. Nitrogen and P, 40 and 45 kg/ha, respectively (200 lbs/A of diamonium phosphate 18-46-0) and K 167 kg/ha (300 lbs/A of potassium chloride 0-0-60) were applied broadcast and disked in.

On June 3, 1982, well-sprouted 35-45 mm diameter seed tubers from 1981 harvest were hand-set in furrows 1.07 m (42 in) apart. In-row spacing varied according to treatment design. Seed was hilled to a planting depth of approximately 15 cm (6 in).

Treatments were arranged in a split-plot, factorial, randomized block experimental design with 3 replications. The whole plot treatments consisted of 2 cultivars: Red Norland, an early red fresh market potato, and Kennebec, a late white fresh market potato. Sub-plots were arranged in factorial combinations of 2 levels of side-dressed N: 0 and 117 kg/ha (103 lbs N/A), 3 within-row spacings 18, 28, and 38 cm (7, 11, and 15 in), and 2 levels of plant maturity at harvest (natural plant senescence and early vine killing). The experimental plot consisted of 3 rows each 6.10 m (20 ft) long and 1.07 m apart for each treatment. The center row was harvested for data collection. Alachlor (Lasso 4EC) at 4.60 kg ai/ha plus linuron (Lorox 50WP) at 1.80 kg ai/ha were applied just prior to potato emergence on June 15 for weed suppression. Normal recommended cultural practices of pest control and irrigation were followed.

Side-dressed N treatments were mechanically applied on July 1 as a lateral band 12.7 cm (5 in) from the plant and 17.8 cm (7 in) deep. The N source was ammonium nitrate, a granular fertilizer with an analysis of 34-0-0.

To determine the N status of the plants, approximately 25 of the most recently matured petioles (4th leaf from the stem tip) were sampled at the full bloom stage of the plants. These samples were taken from the plots corresponding to the natural senescence treatments on July 20 and July 26 for 'Red Norland' and 'Kennebec', respectively. Petioles were dried in a forced air oven at 70 C for at least 72 hours, then ground in a Willey mill to pass a 40 mesh screen. Nitrate nitrogen concentration was determined with a nitrate ion specific electrode.

Early vine killing treatments were applied when the plants had an average tuber size of approximately 35-40 mm diameter, July 28 and August 6 for 'Red Norland' and 'Kennebec', respectively. This physiological stage was determined by random plant samplings of the border rows of the nonside-dressed N and intermediate spacing treatments. The plants were sprayed with a solution of Paraquat at 0.54 kg ai/ha plus Triton X-77 0.52 gal/ha using a 3-gal capacity hand sprayer at the pressure of approximately 2.85 kg/cm^2 (40 lbs/in^2) to obtain complete coverage. A second herbicide application was done a week later to completely kill the basal portions of the stems and to avoid resprouting.

Field observations were also made on growth pattern of the plants according to the treatments.

'Red Norland' was harvested on August 26 and 'Kennebec' on September 24. The harvest stage for the natural senescence treatments was defined as that at which 50% or more of the treatments for each cultivar showed generalized foliage yellowing or browning as senescence symptoms.

After harvest, the tubers were size-graded into the following categories: a) less than 32 mm diameter (small tubers); b) 32-55 mm diameter tubers (standard seed size), and c) tubers with diameter greater than 55 mm (large tubers). The weight of each category was recorded.

Statistical analysis, using analysis of variance and general linear model procedures, measured the effects of cultivar, in-row plant spacing, side-dressed N, and plant maturity at harvest on the response variables.

RESULTS

Tuber yield

Total yield There was a significant interaction (P = .04) between cultivar and in-row plant spacing for total tuber weight (Tables 1 and 2, Figure 1). This interaction is significant because of a higher total tuber weight increase on 'Red Norland', 2.2 mt/ha, compared with only a 0.9 mt/ha increase on 'Kennebec' as plant spacing was increased from 18 to 28 cm (51,884 to 33,357 plants/ha). On the other hand, increasing plant spacing up to 38 cm (24,579 plants/ha) caused a greater total yield reduction on 'Kennebec', 10.6 mt/ha, whereas the yield of 'Red Norland' was less affected (5.7 mt/ha reduction). Statistically significant differences among in-row plant spacings can be described by the second-degree polynomial equation, $\hat{y} = a+bx+cx^2$, where $\hat{y}$ is yield (total tuber fresh wt., mt/ha) and x is in-row plant spacing. This interaction between cultivar and plant spacing can be described using the quadratic equation for each cultivar and calculating the individual predicted maximum (Table 3). Maximum total tuber yield was obtained at about 26 and 24 cm in-row plant spacing for 'Red Norland' and 'Kennebec', respectively.

A significant interaction (P = .01) was present for total yield as affected by cultivar and side-dressed N (Tables 1 and 4). The significance of this interaction is due to a higher total tuber weight increase for 'Red Norland' (9.3 mt/ha) with the 117 kg/ha side-dressed N application, compared to a lower yield increase (4.1 mt/ha) for 'Kennebec' under the same N rate.

Table 1. Analysis of variance for potato tuber weight (mt/ha) of three size categories and total yield as affected by cultivar, side-dressed N, plant spacing and plant maturity at harvest, 1982

		Small		Standard seed size		Large		Total yield[a]	
Source	df	MS	Pr>F	MS	Pr>F	MS	Pr>F	MS	Pr>F
Blocks	2	0.039	.44	1.81	.03	162.77	.001	140.82	.002
Cultivar	1	1.869	<.001	30.42	<.001	3392.13	<.001	2367.80	<.001
Error (a)	2	0.002		0.02		132.62		129.91	
Nitrogen side-dressed (N)	1	0.045	.33	0.03	.79	812.04	<.001	824.18	<.001
Spacing	2	1.735	<.001	80.68	<.001	176.50	<.001	445.70	<.001
Linear	(1)	3.467	<.001	154.08	<.001	74.75	.06	524.01	<.001
Quadratic	(1)	0.003	.79	7.29	<.001	278.61	<.001	367.30	<.001
Maturity	1	2.000	<.001	92.48	<.001	1928.20	<.001	1079.57	<.001
Cultivar*N	1	0.142	.09	1.07	.14	93.38	.03	124.82	.01
Red Norland + N[b] vs. Red Norland - N	(1)	0.180	.28	0.35	.19	727.92	<.001	794.80	<.001
Kennebec + N vs. Kennebec - N	(1)	0.016	.84	1.60	.15	177.29	<.001	153.61	<.001
Cultivar*Spacing	2	0.008	.84	0.65	.27	61.20	.05	65.11	.04
Cultivar*Maturity	1	0.294	.02	0.08	.68	68.05	.07	63.47	.07
Red Norland Nat. Sen.[c] vs. Red Norland E. Mat.[d]	(1)	0.391	.22	49.07	<.001	635.54	<.001	309.90	<.001

Kennebec Nat. Sen. vs. Kennebec E. Mat.	(1)	1.920	.02	90.80	<.001	1359.76	<.001	833.82	<.001
N*Spacing	2	0.080	.19	6.92	<.001	58.63	.06	91.37	.01
N*Maturity	1	0.180	.06	1.39	.09	3.73	.67	6.84	.55
Spacing*Maturity	2	0.271	.006	11.58	<.001	38.38	.16	32.70	.19
Cultivar*N*Spacing	2	0.113	.10	0.73	.23	11.15	.57	6.53	.71
Cultivar*N*Maturity	1	0.467	.003	0.05	.73	2.06	.75	3.12	.69
Cultivar*Spacing*Maturity	2	0.002	.96	1.94	.02	13.00	.52	16.65	.42
N*Spacing*Maturity	2	0.075	.22	2.84	.006	3.84	.82	0.04	1.00
Cultivar*N*Spacing*Maturity	2	0.036	.47	1.17	.10	2.03	.90	0.88	.95
Error (b)	44	0.047		0.48		19.91		19.12	
C.V. (%)		19.3		10.1		16.6		12.5	

[a] Total yield is a combination of all tuber size classes.

[b] N = with 117 kg N/ha side-dressed.

[c] Nat. Sen. = harvested at natural senescence.

[d] E. Mat. = harvested at early maturity.

Table 2. Effect of cultivar, plant maturity at harvest, plant spacing and side-dressed N rate on potato tuber yield of three size categories and total yield, mt/ha, 1982

Plant spacing (cm)	Natural senescence							
	Side-dressed N rate (kg/ha)							
	0				117			
	Small	Seed	Large	Total	Small	Seed	Large	Total
				Red Norland				
18	1.2	8.4	19.0	28.6	1.7	8.1	26.8	36.6
28	1.0	6.1	23.1	30.2	1.2	6.6	31.9	39.7
38	1.0	3.9	15.7	20.6	1.0	4.9	28.4	34.3
Average	1.1	6.1	19.3	26.5	1.3	6.5	29.0	36.9
				Kennebec				
18	1.1	7.3	42.9	51.3	0.9	7.1	41.9	49.9
28	0.8	4.1	40.7	45.6	0.4	4.7	46.0	51.3
38	0.8	3.9	29.0	33.7	0.4	3.5	38.4	42.3
Average	0.9	5.1	37.5	43.5	0.6	5.1	42.1	47.8

Early maturity							
Side-dressed N rate (kg/ha)							
0				117			
Small	Seed	Large	Total	Small	Seed	Large	Total
			Red Norland				
1.6	10.8	10.8	23.2	1.8	8.2	18.2	28.2
1.3	9.0	13.6	23.7	1.7	10.7	19.5	31.9
1.1	6.3	10.6	18.0	0.9	7.1	21.9	29.9
1.3	8.7	11.7	21.6	1.5	8.7	19.9	30.0
			Kennebec				
1.5	9.7	26.3	37.5	1.5	7.6	27.5	36.6
1.1	8.9	28.5	38.5	1.4	8.4	33.6	43.4
0.7	4.2	21.4	26.3	1.0	4.9	28.0	33.9
1.1	7.6	25.4	34.1	1.3	7.0	29.7	38.0

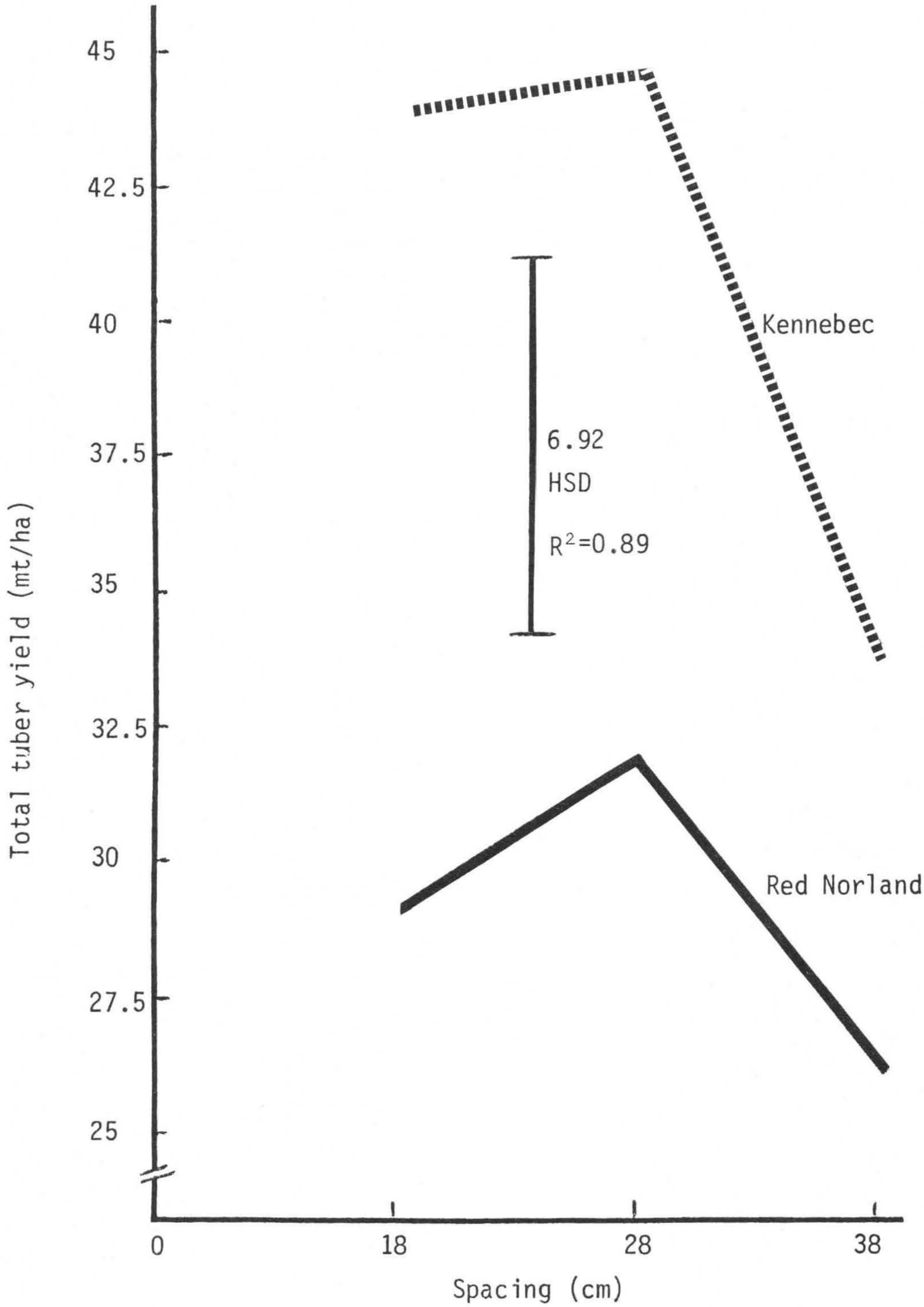

Figure 1. Effect of cultivar and in-row plant spacing on potato total tuber yield, 1982

Table 3. Coefficients of quadratic equation for potato total tuber weight as affected by cultivar and side-dressed N. Spacing (Spac) is the independent variable

	Cultivar		Side-dressed N rate (kg/ha)	
Parameter	Red Norland	Kennebec	0	117
Intercept	5.40	13.99	13.55	5.83
Spac	2.03	2.68	2.02	2.69
$Spac^2$	-0.039	-0.056	-0.045	-0.050
Spac in cm for max y[a]	26	24	24	27

[a]Max y = maximum total tuber yield.

Table 4. Effect of cultivar and side-dressed N on total tuber weight, mt/ha, 1982

	Side-dressed N rate (kg/ha)	
Cultivar	0	117
Red Norland	24.0	33.4
Kennebec	38.8	42.9

A quadratic interaction (P = .01) between side-dressed N rate and plant spacing was also displayed for total tuber weight (Tables 1 and 2, Figure 2). For side-dressed N treated plants, the change of plant spacing from 18 to 28 cm caused a 10.7% increase on total tuber weight, whereas a 1.7% yield reduction was observed with the no N treatment. Increasing plant spacing up to 38 cm, however, reduced total tuber weight by 15.6% and 28.7% for side-dressed N and no N treatment, respectively. Solving the first

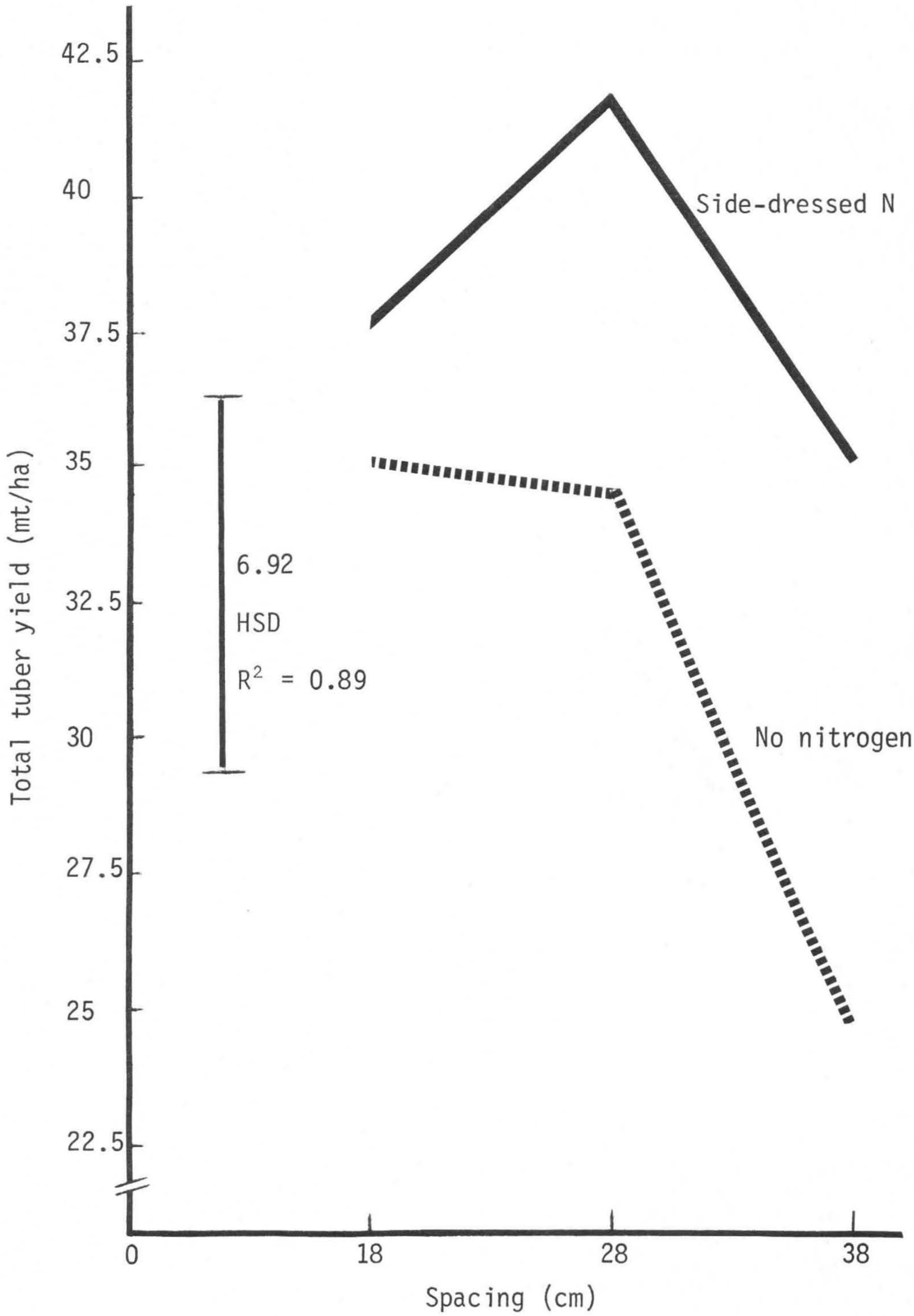

Figure 2. Effect of side-dressed N and in-row plant spacing on potato total tuber yield, 1982

derivative of the quadratic equation for each N level (Table 3) gives a maximum total tuber yield at about 24 and 27 cm plant spacing for the no N and side-dressed N treated plants, respectively.

Overall, harvesting the plants at early maturity caused a 20% reduction on total tuber weight, compared with plants harvested at natural senescence.

Standard seed size There was a significant interaction ($P = .02$) between cultivar, spacing and plant maturity for the seed size tuber weight (Tables 1 and 2, Figure 3). For the early maturity treatment, increasing in-row plant spacing from 18 to 28 cm did not significantly affect the seed size tuber yield with either cultivar (Figure 3). Yield levels were 9.5 and 8.6 mt/ha with plants spaced 18 cm apart and 9.8 and 8.6 mt/ha with those spaced at 28 cm for 'Red Norland' and 'Kennebec', respectively. However, increasing in-row plant spacing up to 38 cm caused a larger yield reduction on 'Kennebec' (4.1 mt/ha) compared with 'Red Norland' (3.1 mt/ha).

With plants harvested at their natural senescence, the yield levels were lower than the early maturity treatment. The seed size tuber weight of 'Red Norland' showed a linear decrease ($P < .001$) described by the equation $\hat{y} = 11.62 - 0.19x$ as plant spacing was increased from 18 to 38 cm. The yield of 'Kennebec', on the other hand, was strongly reduced (2.8 mt/ha) as plant spacing changed from 18 to 28 cm and only slightly affected (0.7 mt/ha reduction) when the in-row plant spacing was increased up to 38 cm. This interaction between cultivar, harvest plant maturity, and in-row plant spacing can be described by the use of the quadratic equation for

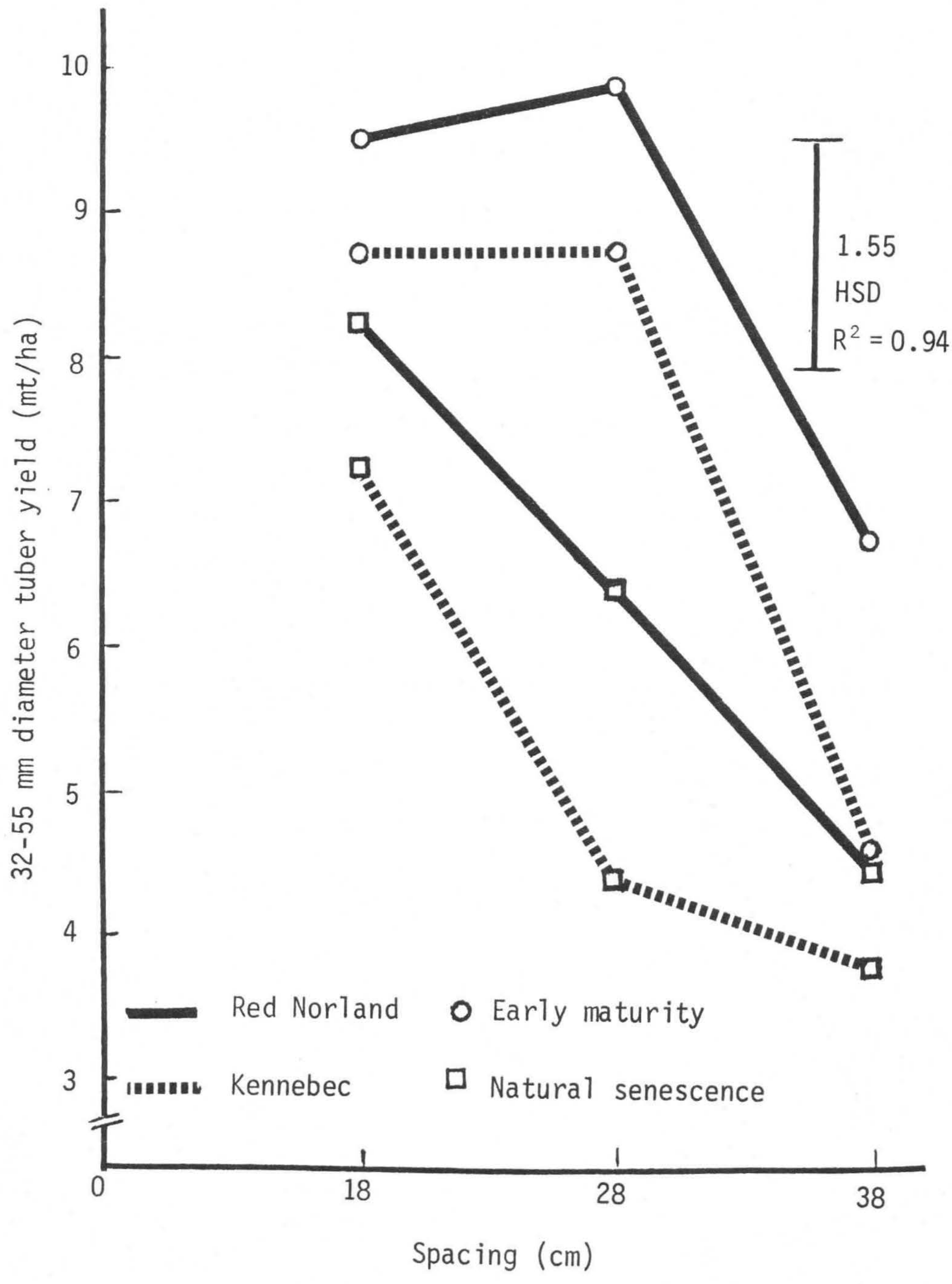

Figure 3. Effect of cultivar, in-row plant spacing and plant maturity on potato 32-55 mm diameter tuber yield, 1982

each cultivar and harvest plant maturity combination (Table 5). For plants harvested at early maturity, maximum seed tuber yields were obtained at 24 and 23 cm plant spacing with 'Red Norland' and 'Kennebec', respectively. On the other hand, 'Kennebec', when harvested at natural senescence, displayed its maximum seed tuber yield at about 18 cm plant spacing.

Table 5. Coefficients of quadratic equation for potato seed-size tuber weight as affected by plant maturity at harvest and cultivar. Spacing (Spac) is the independent variable

	Early plant maturity		Natural senescence
Parameter	Red Norland	Kennebec	Kennebec
Intercept	0.28	-1.46	17.73
Spac	0.82	0.93	-0.78
$Spac^2$	-0.017	-0.020	-0.011
Spac in cm for max y[a]	24	23	18

[a]Max y = maximum seed-size tuber weight.

The seed size tuber weight of 'Red Norland' was higher than that of 'Kennebec' at either harvest maturity. Corresponding mean tuber yields were 6.3 and 5.1 mt/ha for 'Red Norland' and 'Kennebec' harvested at natural senescence and 8.7 and 7.3 mt/ha for each cultivar, respectively, at early maturity harvest.

Seed-sized tuber yield ($P < .001$) increased 37.1% for 'Red Norland' and 42.7% for 'Kennebec' by harvesting the plants at early maturity rather than at their natural senescence.

A significant interaction ($p = .006$) was found between side-dressed N, in-row plant spacing, and harvest plant maturity (Tables 1 and 2, Figure 4). This interaction is significant because of the low yield, 7.9 mt/ha, of the early maturity harvest and 18-cm spacing, with 117 kg/ha side-dressed N treatment, and a corresponding high yield, 10.3 mt/ha, at the same harvest maturity stage and plant spacing without extra N. This interaction can be described using the quadratic equation for each early plant maturity and side-dressed N rate combination and calculating the individual predicted maximums (Table 6). For early maturity harvest, maximum seed tuber yields were found at about 18 and 26 cm plant spacings for the no N and 117 kg/ha side-dressed N treatment, respectively.

Table 6. Coefficients of quadratic equation for potato seed-size tuber weight as affected by early plant maturity at harvest and side-dressed N. Spacing (Spac) is the independent variable

Parameter	Side-dressed N rate (kg/ha) 0	117
Intercept	6.86	-8.04
Spac	0.40	1.35
$Spac^2$	-0.011	-0.026
Spac in cm for max y[a]	18	26

[a]Max y = maximum seed-size tuber yield.

On the other hand, for plants harvested at their natural senescence, there was no significant effect of N level throughout spacings (Figure 4). Therefore, the linear ($P < .001$) decrease on seed tuber weight as plant spacing increased up to 38 cm can be described as an average of the trends for the two N levels by the equation $y = 10.87-0.18x$.

Large   There was a significant interaction ($P = .03$) between cultivar and side-dressed N rate for large tuber yield (Tables 1 and 7). This interaction is significant because of the higher yield increase response on 'Red Norland', 58%, compared with only a 14% increase for 'Kennebec' to the 117 kg/ha side-dressed N application.

Table 7. Effect of cultivar, side-dressed N, and plant spacing on large tuber weight, mt/ha, 1982

Plant spacing (cm)	Side-dressed N rate (kg/ha)	
	0	117
	Red Norland	
18	14.9	22.5
28	18.3	25.7
38	13.1	25.1
Average	15.4	24.4
	Kennebec	
18	34.6	34.7
28	34.6	39.8
38	23.2	33.2
Average	31.5	35.9

Overall, the production of large tubers was 68.8% higher ($P < .001$) for 'Kennebec' compared with 'Red Norland' (Tables 1 and 2, Figure 5).

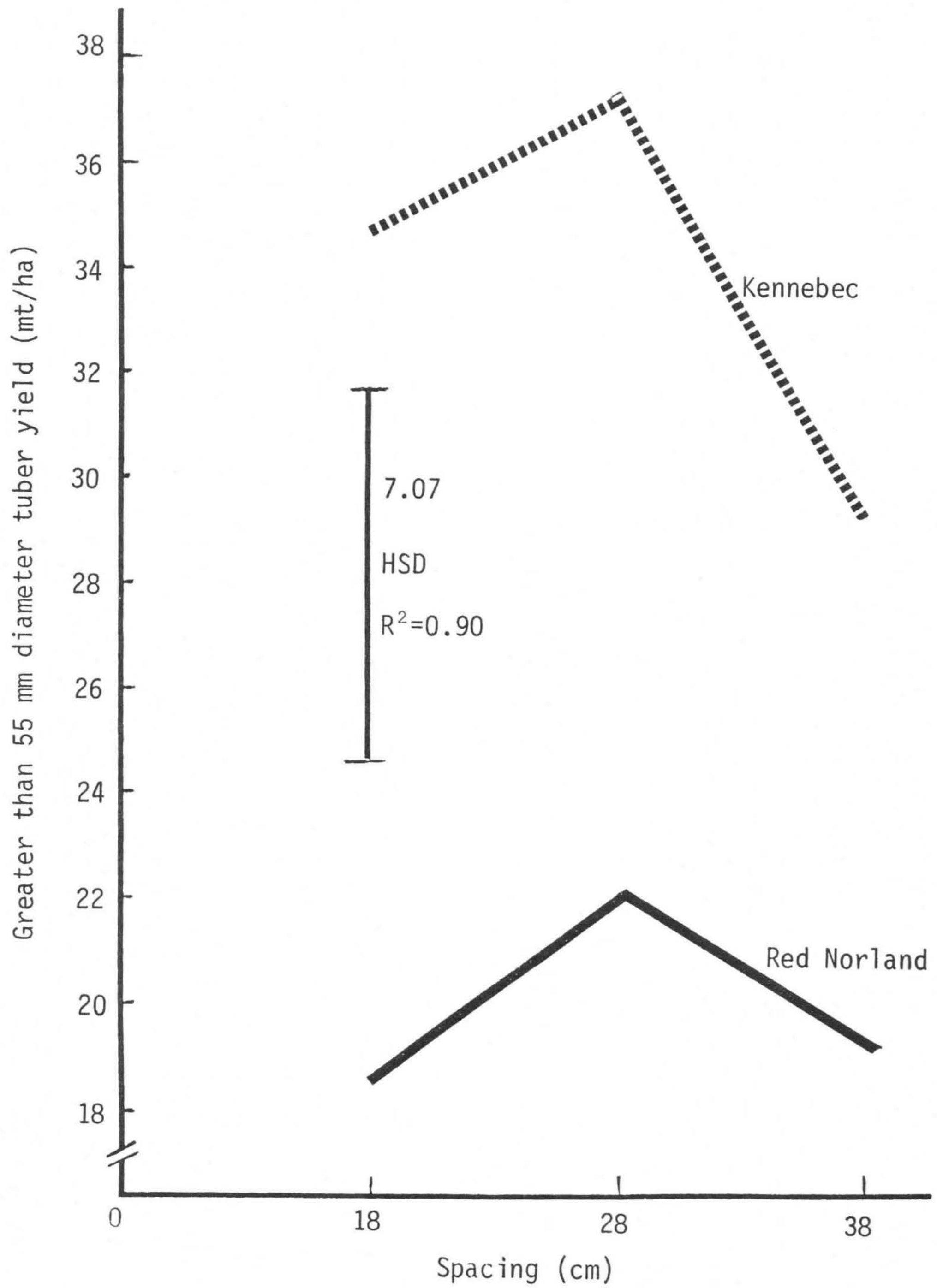

Figure 5. Effect of cultivar and in-row plant spacing on potato greater than 55 mm diameter tuber yield, 1982

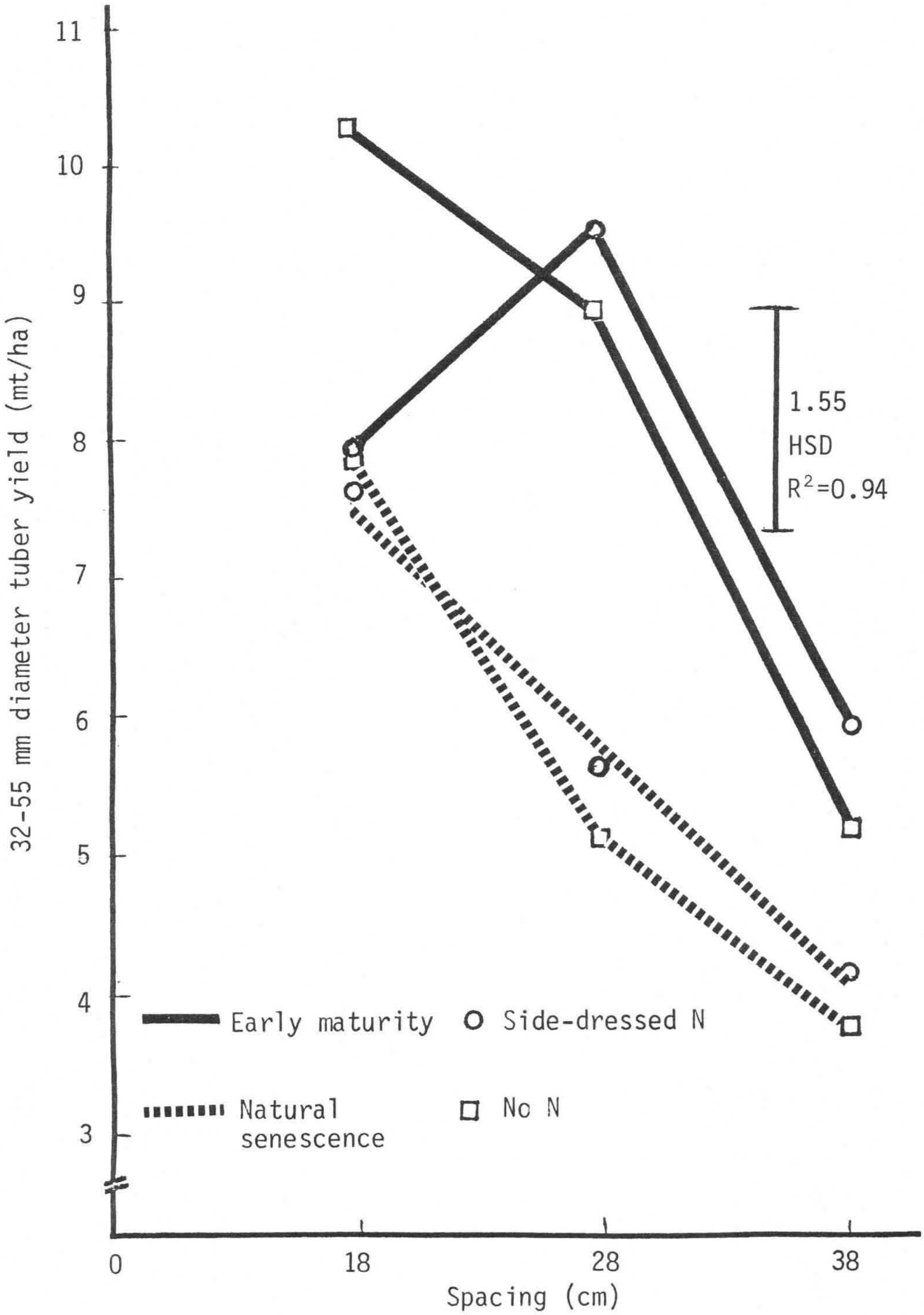

Figure 4. Effect of side-dressed N, in-row plant spacing, and plant maturity on potato 32-55 mm diameter tuber yield, 1982

A significant (P = .05) interaction between cultivar and plant spacing was present for large tuber yield (Tables 1 and 2, Figure 5). The change of plant spacing from 18 to 28 cm caused a similar large tuber yield increase on both cultivars (2.6 mt/ha). However, when plant spacing was increased up to 38 cm, the yield of 'Kennebec' was strongly reduced (8.0 mt/ha), whereas 'Red Norland' was less affected (2.9 mt/ha reduction). Solving the first derivative of the quadratic equation for each cultivar (Table 8) gives a maximum large tuber yield at about 28 and 26 cm plant spacings for 'Red Norland' and 'Kennebec', respectively.

Harvesting the plants at early maturity rather than at their natural senescence caused a 47.7% reduction of the large tuber weight (Tables 1 and 2).

Table 8. Coefficients of quadratic equation for large tuber weight of two potato cultivars. Spacing (Spac) is the independent variable

	Cultivar	
Parameter	Red Norland	Kennebec
Intercept	-2.83	3.57
Spac	1.75	2.67
$Spac^2$	-0.031	-0.052
Spac in cm for max y[a]	28	26

[a]Max y = maximum large tuber yield.

Small The small tuber weight displayed a significant ($P = .003$) interaction between cultivar, side-dressed N, and harvest plant maturity (Table 1, Figure 6). The significance of this interaction is mainly due to a relatively high yield (1.3 mt/ha) for 'Kennebec' with side-dressed N and plants harvested at early maturity compared with a low yield (0.6 mt/ha) obtained for the same cultivar N rate and plants harvested at their natural senescence (Figure 6).

The small tuber yield of 'Red Norland' was superior to 'Kennebec' at either harvest plant maturity.

There was a significant ($P = .006$) interaction between plant spacing and harvest plant maturity for small tuber weight. Plants harvested at early maturity showed a relatively greater yield reduction (0.4 mt/ha) as in-row spacing was increased from 28 to 38 cm compared to a very small yield reduction (0.05 mt/ha) for plants harvested at their natural senescence under the same plant spacing range (Tables 1 and 2). The increase of plant spacing from 18 to 38 cm caused a 34.4% and 42.5% small tuber weight reduction for the natural senescence and early harvest maturity treatment, respectively. In the same way, harvesting the plants at early maturity increased ($P < .001$) the production of small tubers by 35.4% compared to plants harvested at natural senescence.

Petiole NO_3-N concentration

On both cultivars, petiole NO_3-N levels were significantly increased by each increment of the in-row plant spacing from 18 to 38 cm (Table 9). In the same way, the application of 117 kg/ha side-dressed N significantly increased the petiole NO_3-N concentration compared with that observed with

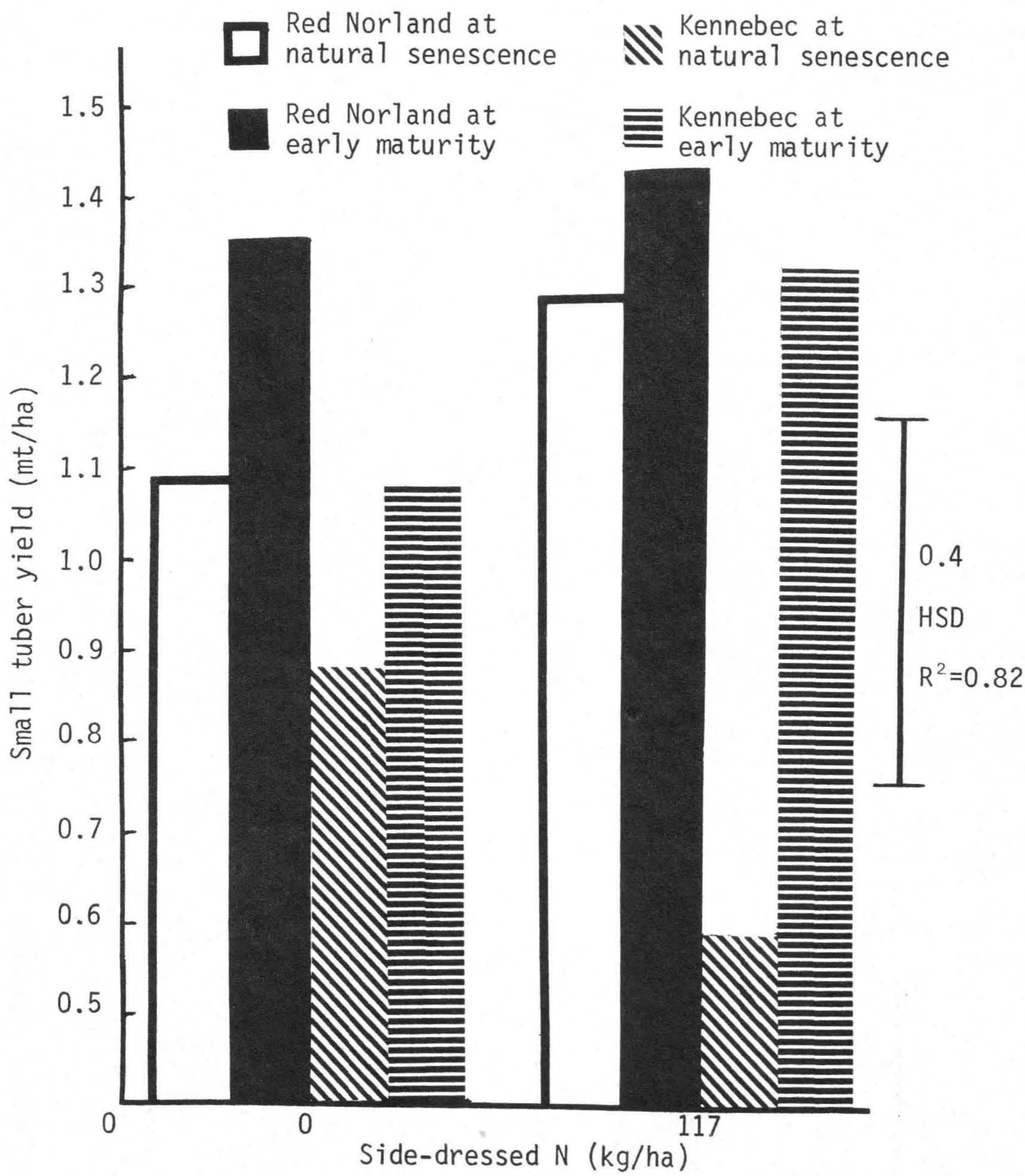

Figure 6. Effect of cultivar, side-dressed N, and plant maturity on potato small tuber yield, 1982

the nonside-dressed N treatments. Overall, the mean petiole NO_3-N concentrations were 9,520 and 9,093 ppm for 'Red Norland' and 'Kennebec' plants that did not receive the extra N application, whereas, for the extra N treated plants, the corresponding values were 22,593 and 22,497 ppm for each cultivar, respectively.

Table 9. Effect of cultivar, in-row plant spacing and side-dressed N rate on potato leaf petiole nitrate concentration (ppm), July 20, July 26, 1982

Plant spacing (cm)	Cultivar			
	Red Norland		Kennebec	
	N rate (kg/ha)			
	0	117	0	117
18	6,640	18,130	6,420	17,210
28	9,400	23,100	8,400	23,600
38	12,520	27,630	12,460	26,680

DISCUSSION

The results of this experiment indicate that the effects of cultivar, in-row plant spacing, side-dressed N rate and plant maturity at harvest on standard seed size tuber yield are not independent. No reports considering the effects of all these factors together on potato tuber yield or size distribution were found in the literature.

Killing potato vines early in the harvest season, before tubers start to approach physiological maturity, is known to reduce tuber specific gravity, average tuber weight, as well as total tuber yield (Findlen and Glaves, 1964; Murphy, 1963). It has also been reported that spacing whole or cut tuber pieces of 60 g weight 15.2 cm (6 in.) apart produced significantly higher yields of standard seed tubers than did 30.5 cm (12 in.) spacings for tuber pieces of the same size (Bishop and Timm, 1968; Banerjee et al., 1978; Warren, 1958; Wilson, 1970). The seed size tuber yield displayed an interaction between cultivar, in-row plant spacing, and harvest plant maturity (Figure 3). As part of this interaction, the slight or no yield difference between plants spaced 18 and 28 cm apart (51,884 and 33,357 plants/ha) when both cultivars were harvested at early maturity can be explained as a result of the combined effect of early harvest and in-row spacing. As shown in Tables A1 and A2 (see Appendix), there was no treatment effect on the number of main stems per plant; therefore, it may be expected that plants spaced 18 cm apart (51,884 plants/ha) with a higher number of stems per unit area competed for growth factors, such as space, light, and nutrient uptake. This competition effect caused not only a reduction in the total and large tuber yield (Figures 1 and 5), but also, a marked decrease in the production of standard seed tubers on those plants that received the extra N application (Table 2, Figure 4).

According to Timm et al. (1963), plants with less than 8,000 ppm of petiole NO_3-N at flowering showed N deficiency symptoms and produced lower yield. Tyler et al. (1961) proposed petiole NO_3-N levels of 9,000 and 6,000 ppm, as sufficiency and deficiency levels, at the same plant developmental stage. In this study, plants that did not receive the side-dressed N at the closest spacings were below the previously suggested critical levels in petiole NO_3-N (Table 9) and, thus, in plant N status. Plants that did receive the extra N were clearly above the critical levels. Therefore, the competition effect in the case of side-dressed N treated plants can be better explained as a reduction in the rate of tuber bulking due to a N increased leaf area index that reduced the amount of carbon assimilates available for developing tubers. Dyson and Watson (1971), with the late cultivar Alpha, found that increasing the rate of N caused an increase in leaf area index and slowed tuber growth during the first 2-3 weeks after tuber formation, but did not affect the time at which the first tubers were formed. Later, N hastened tuber growth by increasing leaf area longevity, and each increment of N increased the dry weight of tubers. Lynch and Rowberry (1977) also reported that the N levels over 100 kg/ha at plant populations over 50,000 plants/ha with the cultivar Russet Burbank increased the leaf area index. At leaf area indices greater than four, almost one-third of the canopy was under the light compensation point, with a concomitant reduction in the net assimilation rate.

The results of this experiment are not in agreement with those of Bodlaender and Reestman (1968) or Van Burg (1967). In the former case, when the late cultivar Alpha was harvested early, total tuber yield and yield of tubers greater than 35 mm increased to an optimum at 100 kg N/ha and 70,000 to 100,000 plants/ha. In the later case, increasing plant population from 40,000 to 70,000 plants/ha in plants harvested early caused an increase in tuber yield. He also found a higher response to applied N up to 175 kg/ha at high, than at low, plant populations. Three factors may have contributed to the competition effect observed at the closest spacings in this study. First, good water supply during the season and relatively warm temperatures, especially in July (Table A3), may have favored foliage growth. Second, with the exception of a slight infection of early blight (*Alternaria solani*) there were no disease problems during the course of the experiment. In the experiments of Bodlaender and Reestman (1968), the early harvest was mainly forced by heavy attacks of late blight (*Phytophthora infestans*); under those conditions, it would be likely that the loss of foliage due to the disease somehow contributed to improve the net assimilation rate of the plants and, in turn, their tuber yield, even at high plant populations and N levels. Thirdly, different cultivars were used in the study. As stated by Thornton and Sieczka (1980), the heavy tuber set of 'Red Norland', as well as the large plant canopy of 'Kennebec', are factors that may have contributed in reducing the net assimilation rate of the plants at the closest spacings.

The improvement of the conditions for plant growth at the 28 cm plant spacing was reflected in a higher petiole NO_3-N concentration (Table 9). For plants harvested early, maximum seed tuber yields were obtained at about

24 and 23 cm plant spacing for 'Red Norland' and 'Kennebec' (Table 5, Figure 3) and at about 18 and 26 cm spacing for no N and side-dressed N treatment, respectively (Table 6, Figure 4). In the same way, total and large tuber yields peaked at plant spacings between 18 and 28 cm (Tables 3 and 8, Figures 1, 2, and 5), whereas the production of small tubers decreased at spacings wider than 18 cm. According to these observations, it will be important in future experiments to evaluate intermediate spacings between 18 and 28 cm. These intermediate in-row spacings will not only require less seed per unit area but, also, can generate a high seed tuber yield and an increased commercial tuber production.

The low seed tuber yield displayed by both cultivars at the 38 cm plant spacing (24,579 plants/ha) is explained by a double effect: first, a condition of no competition at which both cultivars expressed their maximum average tuber size, and, second, a consequence of the total tuber yield reduction due to the lower number of main stems per unit area.

The standard seed-sized tuber yield of plants harvested at their natural senescence was mainly affected by the in-row plant spacing. On both cultivars, as reported by Maas (1963), wider spacings increased the proportion of large tubers, whereas the yield of seed-sized and small tubers was reduced. These observations resemble those of Svenson (1962), who concluded that, at low plant populations, more assimilates will be available for daughter tubers, resulting in maximum average tuber weight for a genotype in that environment, whereas, for high plant populations, the average tuber weight would tend to be lower and more constant.

'Kennebec' has a lower genetic potential to produce medium or small-sized tubers compared to 'Red Norland'. This is considered the cause of its low yield of standard seed tubers at the intermediate spacing when harvested at its natural senescence and at the 38 cm spacing at early harvest (Figure 3), as well as the low yield of small tubers when harvested at natural senescence (Figure 6). Thornton and Sieczka (1980) concluded that cultivars with a tendency to produce oversized and/or set a small number of tubers, such as Kathadin or Kennebec, should be spaced 18-23 cm within the row, whereas cultivars which usually have a heavy tuber set, such as Norchip and Norland, should be spaced further apart in the row -- in some areas, up to 28-46 cm. In this experiment, the differences were small between cultivars on plant spacing required for maximum yield of the two size categories over 32 mm diameter and total tuber yield (Tables 3, 5, and 8). However, there was a consistent trend that described 'Red Norland' as a cultivar that needs to be planted at wider in-row spacings compared to 'Kennebec'.

'Red Norland' was superior to 'Kennebec' on seed size tuber weight at either maturity. This observation agrees with that of Lauer et al. (1963), who reported Red Norland as a cultivar that produces a high percentage of U.S. No. 1 tubers. Thompson and Taylor (1974) worked with the cultivars Pentland Marble, which produces a large number of tubers per plant, and Maris Peer, a normal commercial cultivar. They found that, at maturity, the average tuber size was 45% higher for 'Maris Peer' and the yields of canning-sized tubers (20-40 mm diameter) represented about 50% of the total yield for 'Maris Peer' and over 80% for 'Pentland Marble'.

The seed tuber yield was increased 37.1% on 'Red Norland' and 42.7% on 'Kennebec' by harvesting the plants at early maturity rather than at their natural senescence. Murphy (1963) and Wright and Hughes (1964), working with several cultivars, reported 35 to 45% increments on seed-sized tuber yield by killing the vines of the plants 30 days before natural maturity.

As discussed earlier, the seed size tuber weight of early harvested plants, at the closest spacings, was significantly reduced by the side-dressed N application. Overall, the application of 117 kg/ha side-dressed N increased total and large tuber yield by 21.6 and 28.3%, respectively. At the time of harvest of the natural senescence treatments, the foliage of plants corresponding to the two wider spacings and plants that received the extra N application still did not show senescence symptoms. This should serve as evidence that the extra N increased the tuber bulking period by increasing leaf area longevity. So, an extended tuber bulking period plus a higher net assimilation rate of the plants should explain the high response to the extra N on large tuber production, especially at the intermediate and widest spacings with plants harvested at natural senescence.

'Red Norland' showed a higher total and large tuber yield response to the 117 kg/ha extra N application (Tables 4 and 7). As stated before, this cultivar has a heavier tuber set and smaller plant canopy than that of 'Kennebec'. So, it is likely that, under conditions of a higher leaf area index induced by the extra applied N, these characteristics have contributed in keeping a higher plant net assimilation rate. Dyson and Watson (1974), in experiments conducted in 1963 and 1964, determined that, in both years, the application of 250 kg N/ha at planting caused a 125% increase in leaf area longevity. Leaf area longevity was 21% greater in 1964 than in 1963, and the net assimilation rate was larger; consequently, mean tuber yield was 50% more in 1964. The soil contained approximately 4.6% organic matter and the previous crop was an annual rye, which, through mineralization, released additional N. However, the high response to the extra N application can be explained by a very wet winter and spring and an overall higher than normal rainfall during the growing season (Table A3) that may have favored N leaching losses.

SECTION II. CARRY-OVER EFFECTS OF SIDE-DRESSED NITROGEN AND HARVEST MATURITY ON SEED POTATO (*Solanum tuberosum* L.) PERFORMANCE

PROCEDURES

Seed tubers 35-45 mm diameter from the 28 cm (11 in) in-row plant spacing, 2 levels of N (0 and 117 kg/ha) side-dressed to the seed crop, and 2 levels of plant maturity at seed crop harvest (natural senescense and early maturity) were selected and stored at 3-4 C (38-40 F) and 85-90% HR for 24 days starting August 26 and September 24 for 'Red Norland' and 'Kennebec', respectively. They were then sprouted by exposure on a glasshouse bench for 58 days ('Red Norland') and 101 days ('Kennebec') at day/night temperatures of 22/18 C (72/65 F). Seed tubers were considered sprouted when they had at least 3 sprouts 2 mm or more in length.

On November 6, 1982, and January 28, 1983, for 'Red Norland' and 'Kennebec', respectively, sprouted seed tubers were planted in 20 cm (8 in) plastic pots with a growing medium of hypnum peat, field soil, and perlite (1:1:1 by volume). Treatments were replicated 3 times with 1 plant/pot as the experimental unit.

Plants were grown in a glasshouse with day/night temperature of 22/17 C (72/63 F) and irradiance ranging from 350 to 400 $\mu Em^{-2}sec^{-1}$ (16 hrs photoperiod). Deionized water was used to keep the soil moisture near the field capacity during the course of the experiment. Each week, a soluble fertilizer, with an analysis of 20-20-20, was applied per pot to give 125 mg N-P-K. Plants were thinned to one stem throughout the study.

Response variables were plant emergence, number of stolons, number of tubers, leaf area of 3rd, 5th, and 7th leaf from the stem tip, and shoot dry weight per plant at the 10, 15, 20, and 25 leaf stage of each plant.

RESULTS AND DISCUSSION

Neither side-dressed N nor harvest plant maturity of seed production crop had any effect on subsequent seed tuber dormancy break or plant emergence of the progeny. All treatment combinations in both cultivars showed a 100% plant emergence 12 days after planting. There was also no significant interaction between factors on early plant growth characteristics of the progeny (Figure 7, Table B1). In the same way, no carryover effects were observed on stolon and tuber production, leaf area, or shoot dry weight per plant at any of the other developmental plant stages evaluated (Tables 2B, 3B, 4B).

As expected, significant differences were displayed by the cultivars in leaf area and shoot dry weight throughout the course of the experiment, as well as in the number of tubers per plant at the 25-leaf stage. Mean number of tubers per plant at the 25-leaf stage was 3.9 and 3.3 for 'Red Norland' and 'Kennebec', respectively. These differences are explained by the different genetic characteristics of growth and yield in each of the cultivars, which were fully discussed in Section I. Stolon formation occurred about 30 and 32 days after planting (near the 15-leaf stage) on 'Red Norland' and 'Kennebec' (Figure 8), whereas tubers appeared approximately 54 and 58 days after planting (close to the 25-leaf stage) on each cultivar, respectively.

In regard to seed crop harvest plant maturity, Hutchinson (1978) and O'Brien and Allen (1975) reported that seed tubers from early harvested crops showed a shorter dormant period and gave earlier and more uniform emergence when the tubers were placed in conditions suitable for sprouting

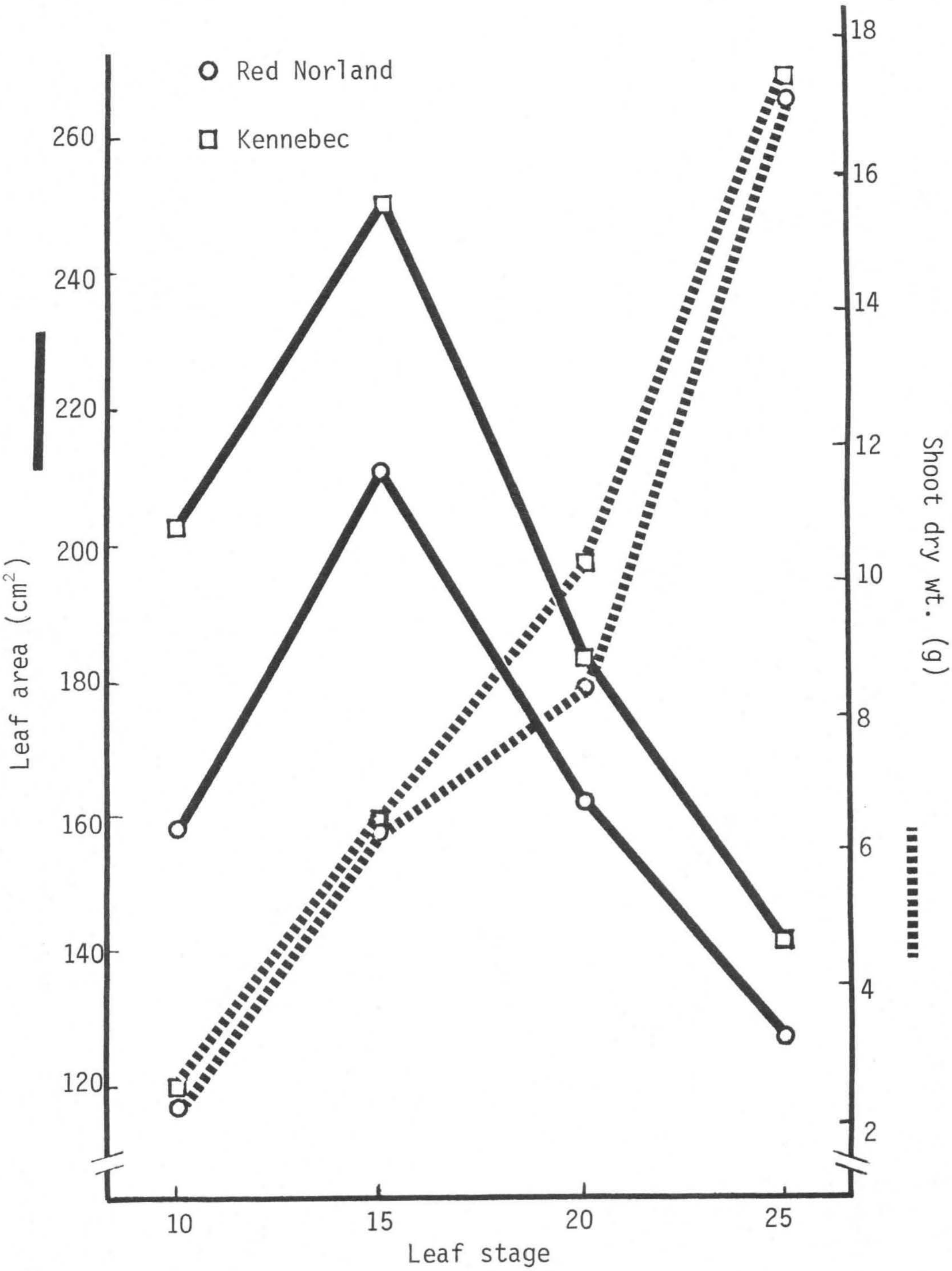

Figure 7. Differences between leaf area and shoot dry weight of two potato cultivars evaluated at 4 different developmetnal stages of the progeny

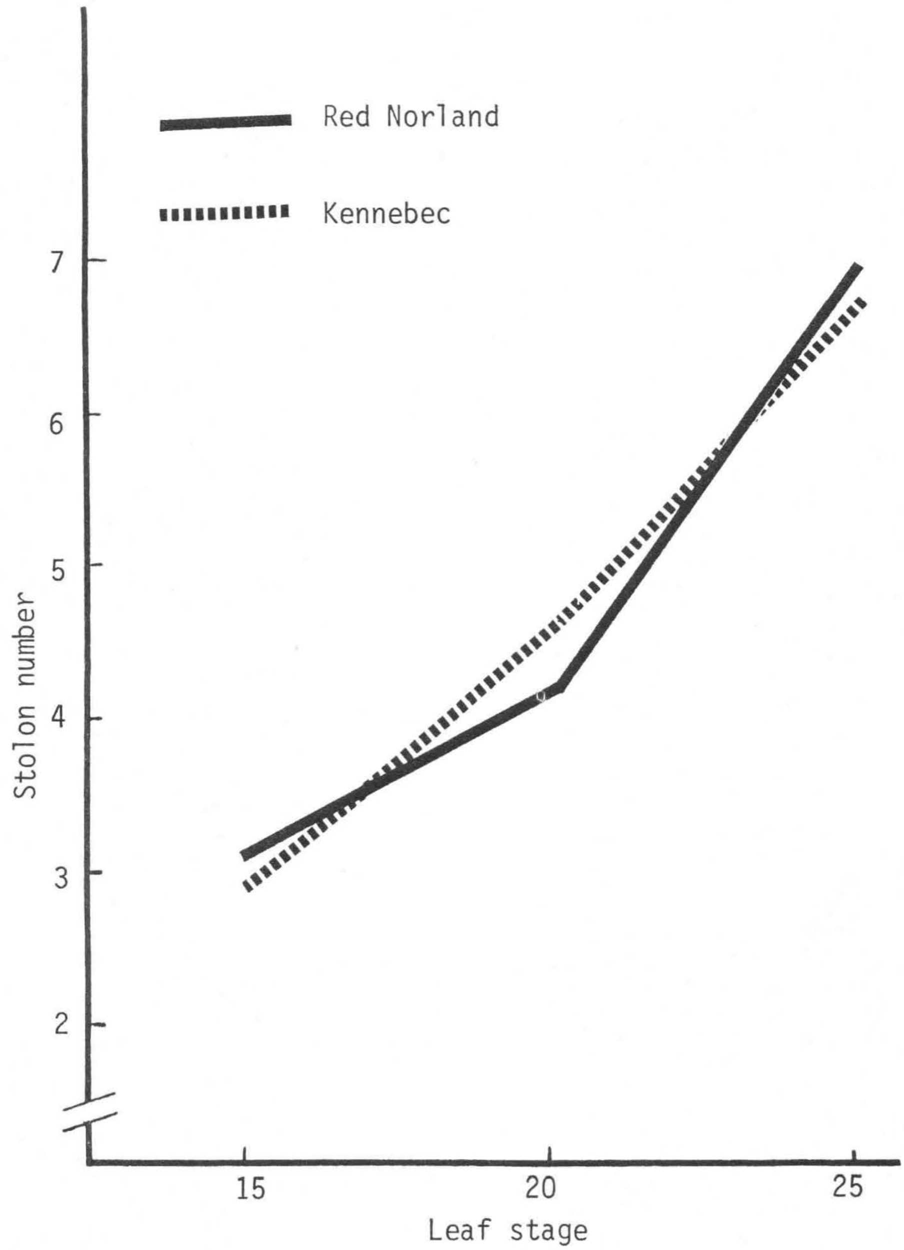

Figure 8. Number of stolons of two potato cultivars evaluated at three different developmental stages of the progeny

immediately after lifting. However, the results of the experiment described here agree with those of Murphy et al. (1967), who found no differences in plant emergence when tubers of different maturities were stored at 0 to 3.3 C and then sprouted at 20 C prior to planting. The findings of this experiment can be explained by the observations of Krijthe (mentioned by Holmes and Gray, 1972), who found, while working with 36 cultivars, that storage temperatures below 5 C retarded sprout growth in some varieties more than in others. Tubers of any cultivar from the same field, harvested on different dates, showed only small differences in the rate of sprout growth. The greatest difference was found between harvesting very immature and mature tubers. Immature tubers had a slightly shorter dormant period and more rapid growth than mature tubers.

Holmes and Gray (1972) and Murphy et al. (1967) produced seed of differing maturity dates by planting sprouted versus unsprouted mother tubers or by destroying foliage of the seed crop 2-3 weeks before senescence versus allowing natural senescence. Small differences in sprout growth were recorded, but none of the treatments applied to the first generation crop affected the time of emergence, stem number, growth of the foliage, or tubers in the second generation crop. Godwin et al. (1969) showed that, even for the early commercial crop, variation in the maturity of the seed crop caused by different dates of harvest had little effect on the subsequent crop, when the different seed lots were well-sprouted under the same conditions before planting.

Seed tubers from both plant maturity stages were harvested in the same size range (32-55 mm diameter). Therefore, it is expected that the main differences in developmental or physiological condition between the seed tubers of each harvest maturity stage arise from the period between elimination of the vines in the early maturity treatments and the harvest date (29 and 49 days for 'Red Norland' and 'Kennebec', respectively). This was the period at which the early maturity seed tubers remained "stored" in the soil. However, it is likely that the cool storage treatment (3-4 C) immediately after harvest, as well as the preplant sprouting, may have contributed to the elimination of possible initial differences in physiological maturity between the two seed lots. Furthermore, the fact that there were no significant insect problems during the growing season of the seed crop negated the possible advantages of getting virus-free seed tubers by an early harvest, as reported by Hossain and Rybacek (1978).

Gray (1974) concluded that the effects of nitrogen applied to the seed crop on subsequent growth other than that related to seed tuber size arose only as a result of effects on the maturity of the seed crop. Thus, any observed effect is attributed to differences in the "physiological age" of seed rather than to differences in seed tuber N-reserves. Schepers et al. (1969) reported that only in some cases were slight differences observed in development between the progeny in fields with varied N application. These differences, however, disappeared soon after emergence. The disappearance of initial differences in development may indicate that recently emerged plants change from feeding off the mother-tuber to uptake of nutrients from the soil. Experiments elsewhere agree with this assumption. Morris (1967) found that sprouts of recently planted tubers with initial root-growth are able to take up nutrients from the surrounding medium and that the competition for nutrients from the mother-tuber could be reduced by supplying nutrients to this medium. The observation that sprouts having root primordia before planting dominate in growth over smaller sprouts without root primordia (Schepers and Hoogland, 1968, mentioned by Schepers et al., 1969) indicates a rapid uptake of nutrients from the soil soon after planting.

The possible initial differences in physiological maturity of the seed tubers were apparently cancelled by the storage and preplant sprouting conditions. Any improvement in quality is likely to be unimportant when compared with the effects of applied N on seed quantity.

SUMMARY AND CONCLUSIONS

Potatoes (*Solanum tuberosum* L.) were grown on a central Iowa, silty, clay loam soil to evaluate cultivar differences, side-dressed N, in-row plant spacing, and harvest plant maturity on standard seed size (32-55 mm diameter) tuber production. Treatments consisted of 2 cultivars (Red Norland, an early, red, fresh market potato, and Kennebec, a late, white, fresh market potato), 2 levels of side-dressed N (0 and 117 kg/ha), 3 in-row plant spacings (18, 28, and 38 cm), and 2 levels of plant maturity at harvest (natural plant senescence and early harvest maturity). The main factors affecting the seed size tuber yield were harvest plant maturity, in-row plant spacing, and cultivar. It was also found that the effects of these factors are not independent. Seed-size tuber weight displayed an interaction between cultivar, in-row plant spacing, and harvest plant maturity. A quadratic trend for maximum standard seed tuber yield of plants harvested at early maturity was found at about 24 and 23 cm in-row plant spacing for 'Red Norland' and 'Kennebec', respectively. There was also an interaction between nitrogen, plant spacing, and harvest maturity for the seed size tuber weight. For early maturity harvest, maximum yield of seed tubers was found at approximately 18 cm plant spacing with no N and 26 cm plant spacing with the 117 kg/ha side-dressed N treatment. The seed size tuber weight of plants harvested at natural senescence was mainly affected by the in-row plant spacing. In both cultivars, plants spaced 18 cm apart showed the highest seed yields. Wider spacings increased the proportion of large tubers while it reduced that of seed size and small tubers.

Quadratic trends were also observed for maximum total tuber weight at around 26 and 24 cm plant spacing for 'Red Norland' and 'Kennebec' and 24 and 27 cm spacing for no N and side-dressed N treated plants. On the other hand, large tuber weight peaked around 28 cm plant spacing for 'Red Norland' and 26 cm spacing for 'Kennebec', whereas the highest yield of small tubers for both cultivars was found at the 18 cm in-row plant spacing. According to these findings, it will be important in future experiments to evaluate intermediate plant spacings between 18 and 28 cm, especially with early harvested plants. These intermediate spacings will not only require less seed per unit area but, also, can generate a high seed tuber yield and increased commercial tuber production.

'Red Norland' was superior to 'Kennebec' on seed size tuber yield at either harvest maturity. Mean seed tuber yields were 6.3 and 5.1 mt/ha for 'Red Norland' and 'Kennebec' when harvested at natural senescence and 8.7 and 7.3 mt/ha for each cultivar at early harvest. On the other hand, seed tuber weight was increased 37.1% for 'Red Norland' and 42.7% for 'Kennebec' by harvesting the plants at early maturity rather than at natural senescence.

Overall, the side-dressed N application increased total and large tuber weight by 21.6% and 28.3%, respectively. With plants harvested at natural senescence, there was no signficiant effect of N on seed tuber weight. However, the effect of side-dressed N on seed tuber yield of plants harvested at early maturity varied according to the in-row plant spacing. This fact makes it important to consider the history of the plot related to N fertility, when planning future experiments to evaluate more deeply the effects of the other factors on potato seed production under local conditions.

Selections of 35-45 mm diameter seed tubers from 'Red Norland' and 'Kennebec' were taken from the 28 cm in-row plant spacing at 2 levels of N (0 and 117 kg/ha) side-dressed to the seed crop and 2 levels of plant maturity at seed crop harvest (natural senescence and early maturity). They were then stored at 3-4 C and 85-90% HR for 24 days. After storage, they were sprouted and grown in a glasshouse with day/night temperatures of 22/17 C and irradiance ranging from 350 to 400 $\mu Em^{-2}sec^{-1}$ (16 hr photoperiod). Early plant growth characteristics, as well as stolon and tuber initiation of the progeny, were not affected by side-dressed N or harvest plant maturity of seed production crop. Therefore, it is concluded that, when standard seed tubers are stored at 3-4 C immediately after harvest and then adequately sprouted before planting, the amount of N applied to the seed crop and the seed crop harvest plant maturity are of little importance for the productivity of the progeny.

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APPENDIX A.

COMPLEMENTARY DATA AND ANALYSIS OF VARIANCE FOR SOME DATA OF THE FIELD EXPERIMENT (SECTION I)

Table A1. Effect of cultivar, in-row plant spacing, and side-dressed N rate on potato number of main stems per plant,[a] July 20, July 26, 1982

Plant spacing (cm)	Cultivar: Red Norland, Sid. N (kg/ha)[b] 0	Red Norland, 117	Kennebec, Sid. N (kg/ha) 0	Kennebec, 117
18	4.67	4.67	4.58	4.58
28	4.75	4.58	4.58	4.67
38	4.58	4.67	4.75	4.67

[a]Number of main stems per plant = mean of five plants per treatment per replication.

[b]Sid. N (kg/ha) = side-dressed N rate (kg/ha).

Table A2. Analysis of variance for potato number of main stems per plant as affected by cultivar, side-dressed N rate, and plant spacing, July 20, July 26, 1982

Source	df	Mean square
Blocks	2	0.0989
Cultivar	1	0.0017
Error (a)	2	0.0434
Sid. N rate[a]	1	0.0017
Spacing	2	0.0052
Cultivar*Sid. N rate	1	0.0017
Cultivar*Spacing	2	0.0225
Sid. N rate*Spacing	2	0.0017
Cultivar*Sid. N rate*Sapcing	2	0.0330
Error (b)	20	0.0503
C.V. (%)		6.15

[a]Sid. N rate = side-dressed N rate.

Table A3. Monthly rainfall and average temperature during the 1982 growing season (temperature data taken at the Agronomy Farm and rainfall at the Horticulture Research Station, Ames, Iowa)

	Temperature (degrees C)		Rainfall (mm)	
Month	1982	Deviation from normal[a]	1982	Deviation from normal[a]
April	7.4	-2.3	72.90	-8.38
May	17.2	+1.4	200.15	+85.85
June	18.5	-2.2	93.98	-53.34
July	23.4	+0.3	125.22	+42.93
August	21.5	-0.7	146.81	+55.37
September	17.2	-1.2	42.93	-38.35

[a]Deviations from normal were calculated using data reported by Shaw et al. (1954).

APPENDIX B.

ANALYSIS OF VARIANCE OF THE GLASSHOUSE EXPERIMENT DATA

(SECTION II)

Table B1. Analysis of variance for some plant growth characteristics of the progeny at the 10-leaf stage as affected by side-dressed N applied to the seed crop and plant maturity at seed crop harvest, 1982-1983

Source	df	Mean squares: Leaf area per plant[a]	Mean squares: Shoot dry wt per plant
Cultivar	1	12,167.1**	0.2795**
Nitrogen	1	16.5	0.0126
Maturity	1	6.2	0.0287
Cultivar*nitrogen	1	8.8	0.0015
Cultivar*maturity	1	71.9	0.0040
Nitrogen*maturity	1	128.8	0.0001
Cultivar*nitrogen*maturity	1	115.6	0.0009
Error	16	42.2	0.0282
CV (%)		3.6	6.9

[a]Leaf area/plant = leaf area of the 3rd, 5th, and 7th leaves from the stem tip per plant.

**Significant at the .01 level.

Table B2. Analysis of variance for some plant growth characteristics of the progeny at the 15-leaf stage as affected by side-dressed N applied to the seed crop and plant maturity at seed crop harvest, 1982-1983

		Mean squares		
Source	df	Leaf area/plant[a]	Shoot dry wt/plant	No. of stolons/plant
Cultivar	1	9236.3**	0.4845*	0.1667
Nitrogen	1	10.6	0.0001	0.0001
Maturity	1	1.5	0.2795	0.1667
Cultivar*nitrogen	1	28.0	0.2542	0.1667
Cultivar*maturity	1	9.7	0.1080	0.0001
Nitrogen*maturity	1	82.7	0.0759	0.1667
Cultivar*nitrogen*maturity	1	27.7	0.0247	0.0001
Error	16	47.7	0.0874	0.0833
CV (%)		3.0	4.7	9.6

[a]Leaf area/plant = leaf area of the 3rd, 5th, and 7th leaves from the stem tip per plant.

*Significant at the .05 level.

**Significant at the .01 level.

Table B3. Analysis of variance for some plant growth characteristics of the progeny at the 20-leaf stage as affected by side-dressed N applied to the seed crop and plant maturity at seed crop harvest, 1982-1983

		Mean squares		
Source	df	Leaf area/plant[a]	Shoot dry wt/plant	No. of stolons/plant
Cultivar	1	2,688.2**	19.1888**	1.04
Nitrogen	1	2.3	0.0560	0.37
Maturity	1	6.6	0.0640	0.04
Cultivar*nitrogen	1	12.4	0.0140	0.04
Cultivar*maturity	1	10.3	0.0001	0.04
Nitrogen*maturity	1	57.8	0.0241	0.04
Cultivar*nitrogen*maturity	1	9.7	0.0013	0.04
Error	16	18.6	0.0366	0.25
CV (%)		2.5	2.0	11.4

[a]Leaf area/plant = leaf area of the 3rd, 5th, and 7th leaves from the stem tip per plant.

**Significant at the .01 level.

Table B4. Analysis of variance for some plant growth characteristics of the progeny at the 25-leaf stage as affected by side-dressed N applied to the seed crop and plant maturity at seed crop harvest, 1982-1983

Source	df	Mean squares			
		Leaf area per plant[a]	Shoot dry wt/plant	No. of stolons/plant	No. of tubers/plant
Cultivar	1	1050.20**	0.9087**	0.37	2.6667**
Nitrogen	1	0.06	0.2301	0.04	0.0001
Maturity	1	1.45	0.0187	0.37	0.1667
Cultivar*nitrogen	1	0.53	0.0002	0.37	0.6667
Cultivar*maturity	1	0.06	0.1335	0.37	0.1667
Nitrogen*maturity	1	3.73	0.1890	2.04	0.1667
Cutlivar*nitrogen*maturity	1	5.36	0.3528	1.04	0.1667
Error	16	4.85	0.1039	0.71	0.2083
CV (%)		1.6	1.9	12.4	12.4

[a]Leaf area/plant = leaf area of 3rd, 5th, and 7th leaves from the stem tip per plant.

**Significant at the .01 level.